SPIE 5168-35
Constellation-X Spectroscopy X-Ray Telescope Optical Assembly Pathfinder Image Error Budget and Performance Prediction

Dr. William A. Podgorski(SAO)

Co-authors:

Dr. Jay Bookbinder (SAO)

Dr. David Content (NASA/GSFC)

Mr. William Davis (SAO)

Mr. Mark Freeman (SAO)

Mr. Jason Hair (NASA/GSFC)

Dr. Scott Owens (NASA/GSFC)

Dr. Robert Petre (NASA/GSFC)

Dr. Paul Reid (SAO)

Dr. Timo Saha (NASA/GSFC)

Mr. Jeffrey Stewart (NASA/GSFC)

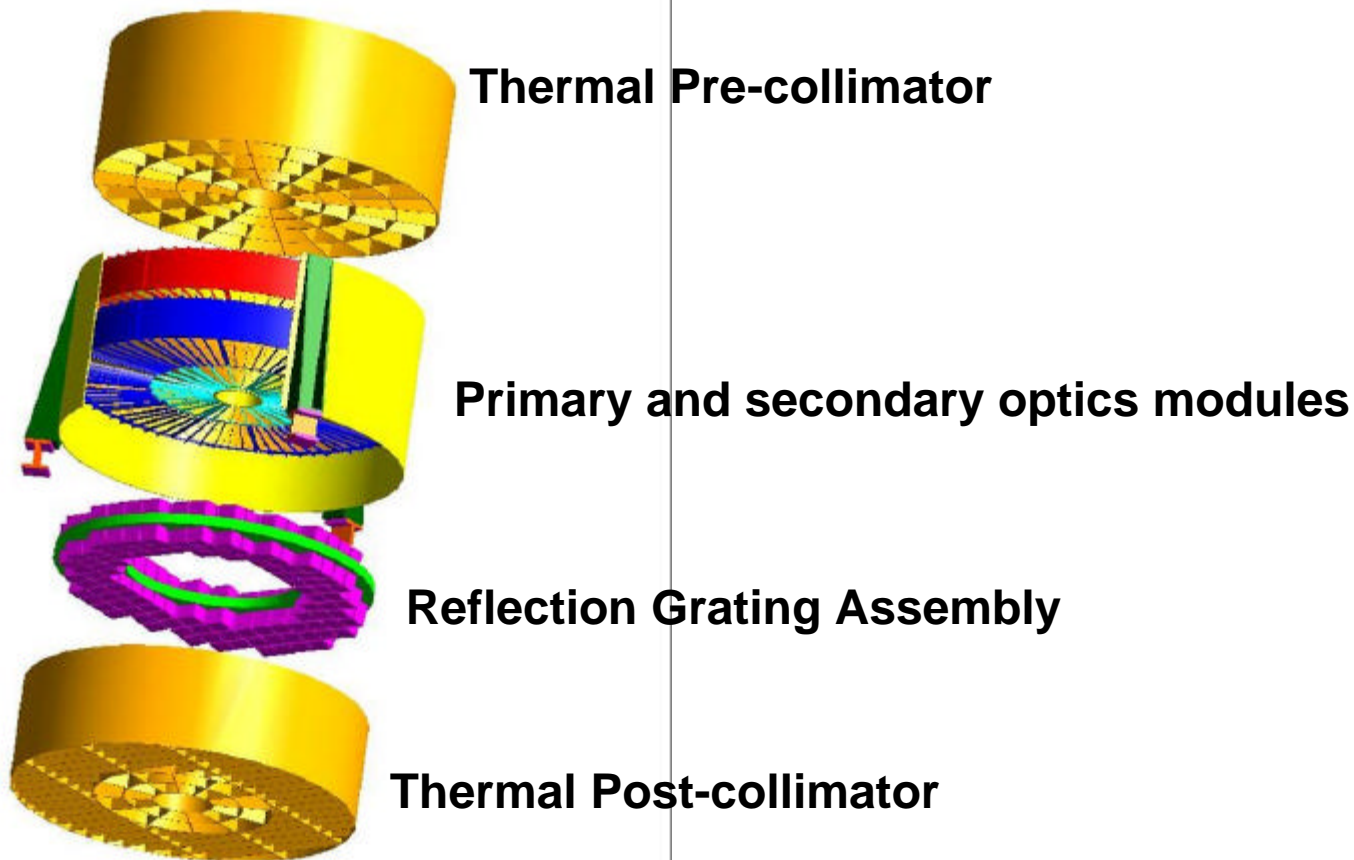**Dr. William Zhang (NASA/GSFC)**

August 7, 2003

Overview

- **SXT Flight Mirror Assembly (FMA) has top level requirement for Image Resolution of 15 arc-seconds (HPD)**
  - **FMA Error Budget Includes Contributors for:**
    - **As-built FMA (~12 arc-seconds HPD)**
    - **FMA on-orbit errors**
    - **Telescope errors**
    - **Detector errors**
    - **Co-add effects (4 satellites)**

- OAP2 is second in a series of developmental SXT optical pathfinders **(see 5168-21, R. Petre et. Al.):**
  - **Specified to have the same <u>as-built</u> image resolution as FMA but for a single shell**
  - **Plan to evaluate image resolution of OAP2 in x-ray test**
  - **Gravity and thermal effects in the x-ray test could limit our ability to demonstrate image resolution performance**
  - **Will report on work done to evaluate these effects.**

Constellation-X

Thermal Pre-collimator

Primary and secondary optics modules

Reflection Grating Assembly

Thermal Post-collimator

Constellation-X

SXT Flight Mirror Assembly - Image Error Budget

Contributors (HPD - arcsec)	Rqmt	Margin	Allocations					Rationale
RGS Resolution	15.00	3.92	14.48					4 satellites, post-processed
▪ Co-add 4 satellites				1.00				Superposition of data using X-ray centroids
▪ On-Orbit Telescope - single satellite				14.12				RSS
▪ CCD pixelization error				0.41				0.5 arcsec pixels
▪ Grating resolution error				3.00				Estimate
XMS Resolution	15.00	4.95	14.16					4 satellites, post-processed
Co-add 4 satellites				1.00				Superposition of data using X-ray centroids
On-Orbit Telescope - single satellite			14.12					RSS
▪ Calorimeter pixelization error					4.08			5 arcsec pixels
▪ Telescope level effects					5.20			RSS
- Image reconstruction errors (over obs)						4.24		RSS
- SXT/Telescope mounting strain						2.00		Eng. estimate based on Chandra experience
- SXT/SI vibration effects						2.00		Chandra experience (jitter)
- SXT/SI misalignment (off-axis error)						1.00		Chandra experience
- SXT/SI focus error						0.20		Analysis
▪ SXT FMA - on-orbit performance					12.48			RSS
- SXT FMA launch shifts						2.00		Eng. est. based on Chandra
- Thermal errors						2.24		RSS
- Material stability effects						1.00		Est. based on Chandra work
- SXT FMA, as built						12.07		RSS
-- Gravity release							1.50	FEA analysis using vertical assy
-- Bonding strain							3.00	Eng. estimate, analysis in process
-- Alignment errors (using CDA)							3.38	RSS
-- Installation in housing							5.00	Est. based on OAP1 testing
-- Optical elements							9.90	Est. based on tech dev program

Requirement – 15 arc-seconds HPD

Constellation-X

Optical Elements - Budget Allocations					
Error Term	**Allocation**	**Sensitivity**	**Allocation**	**Units**	**Definition**
	HPD	HPD/Unit	Unit		
Optical Elements-Total	9.90				
Sag	3.00	25.00	0.12	µm	Peak-Valley
Axial Figure	9.07	3.84	2.36	arc-sec	RMS Slope errors
Roundness	0.75	0.15	5.00	µm	Peak-Valley
ΔΔR	2.47	3.50	0.71	arc-sec	Peak-Valley
Circularity	0.28	0.03	9.90	µm	See 2.2.4
Average Radius	0.00	0.00	±33.00	µm	See 2.2.5
Cone Angle	0.00	0.00	±10.00	arc-sec	See 2.2.5

Table 1 – Optics Error Allocations

Largest contributor is Axial Figure

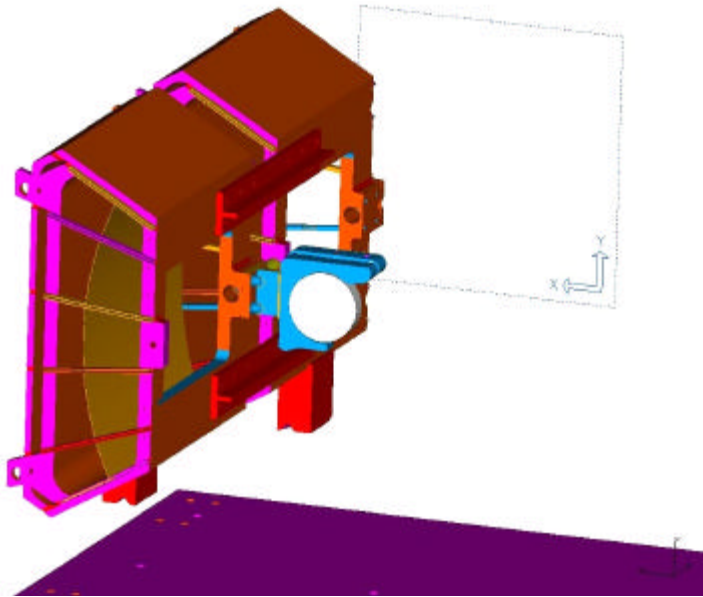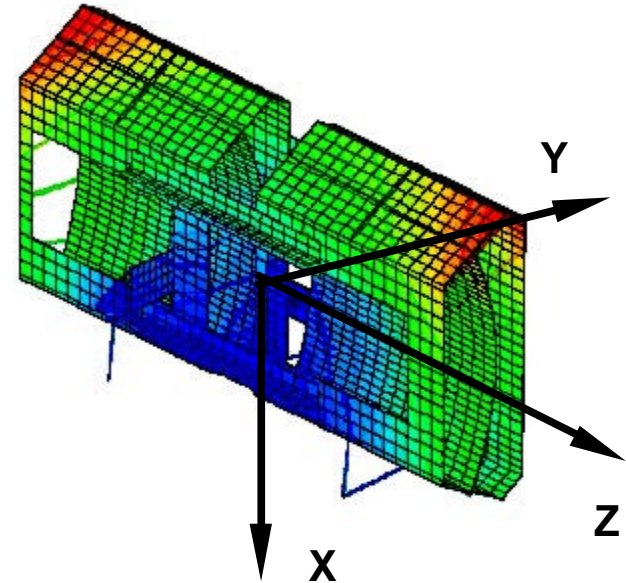| Contributors (HPD - arcsec)	Estimate/Prediction					Rationale/Comments
Image Resolution — OAP2 X-Ray Test	14.34					RSS
X-Ray Test Errors		7.42				RSS
Gravity Distortion			7.00			
Test Equipment errors			1.00			
Finite Source Distance			1.00			
X-ray Source spot size			2.00			1 mm spot
OAP2 Thermally Driven Errors		1.48				RSS
Average Temperature Offset			0.30			1 Degree C Temperature offset
Epoxy/glass bi-layer effects			1.00			20μm EP301/400μm glass, 1 Degree C Offset
Axial Gradient			0.10			0.5 degree end-to-end gradient
Transverse Gradient			0.73			0.1 degree inner wall to outer wall gradient
Vertical Gradient			0.75			0.5 degree top to bottom gradient
Material Stability effects		1.00				Estimate
OAP2 As Built		12.07				Analysis
Gravity release			1.50			FEA analysis using vertical assy
Bonding strain			3.00			Eng. estimate, analysis in process
Alignment errors (using CDA)			3.38			RSS
CDA Dynamic Accuracy				0.76		
CDA Static Accuracy				1.68		
Thermal Drift				2.00		
Adjustment Accuracy				2.00		
Installation in housing			5.00			Est. based on OAP1 testing
Optical elements			9.90			Est. based on tech dev program

SXT OAP2 Image Error Contributors

- **Error contributors unique to testing OAP2 on the ground:**
  - **X-ray test errors including large gravity error**
  - **Thermally driven errors different from on-orbit thermal**
- **Analysis work performed to select best x-ray test orientation and evaluate impacts of 1G on image resolution**
- **Analysis work done to evaluate OAP2 image resolution sensitivities to thermal effects:**
  - **Average temperature offset from assembly temperature**
  - **Temperature gradients**
- **Thermal control system needed to limit these thermal impacts**
- **Planning done to evaluate these effects during x-ray testing**

Constellation-X

OAP2 FEA Model – in x-ray test orientation

OAP2 is a single shell prototype with Titanium housings. Alignment using CDA at GSFC
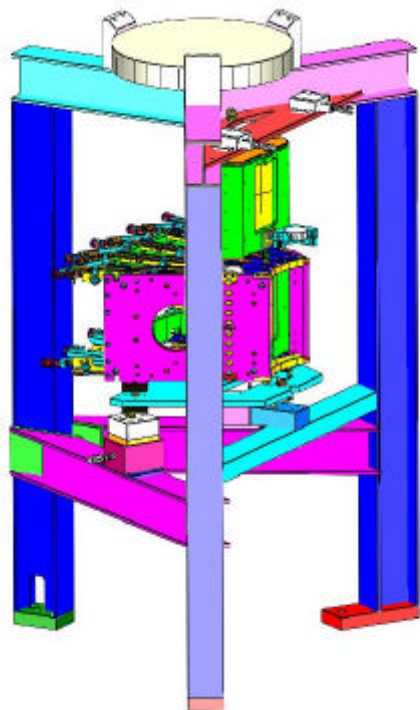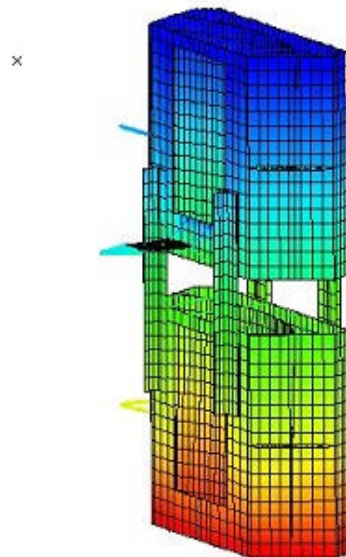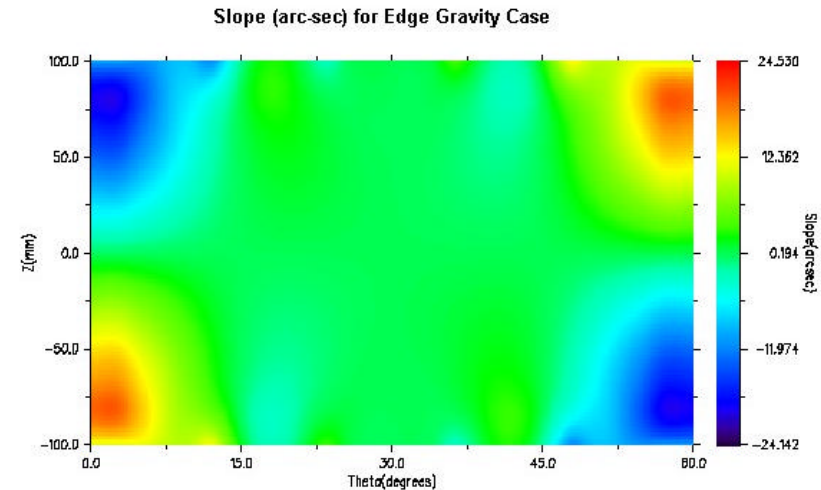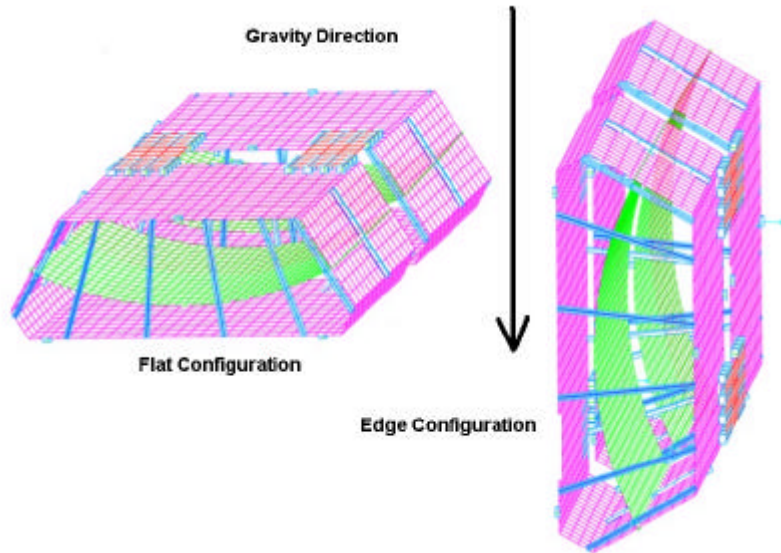
OAP2 in vertical assembly facility

**Gravity effects during vertical assembly add
1.5 arc-seconds (HPD) – in quadrature**

OAP2 FEA Model – Assembly Orientation

Gravity Direction

Flat Configuration

Edge Configuration

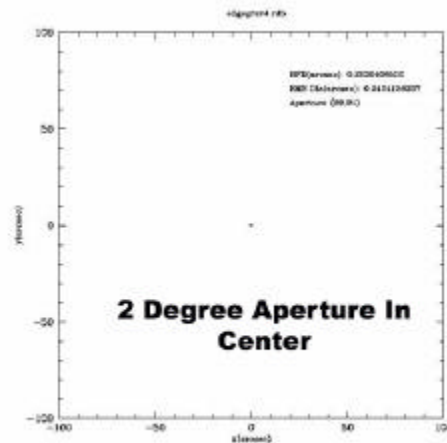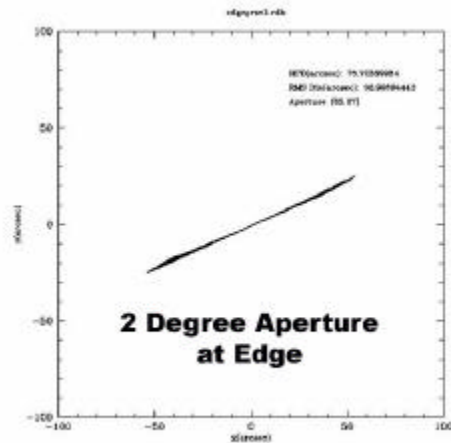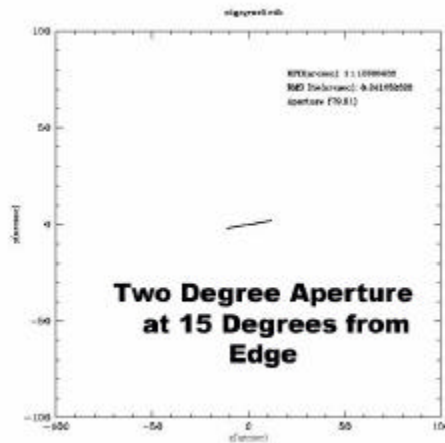Slope (arc-sec) for Edge Gravity Case

OAP2 X-Ray Test Orientation:
- **Two orientations evaluated**
- **"Edge" Configuration selected based on performance**

Gravity distortions are highly localized towards optic edges, allowing us to use a small aperture in the center to eliminate these effects

Load Case	HPD(50 Deg Aperture)
1G Vertical, baseline support	1.5
1G On edge (baseline)	7.0
1G flat	17.6

Gravity Distortion in X-ray Image

Full Image

Two Degree Aperture at 15 Degrees from Edge

2 Degree Aperture at Edge

2 Degree Aperture In Center
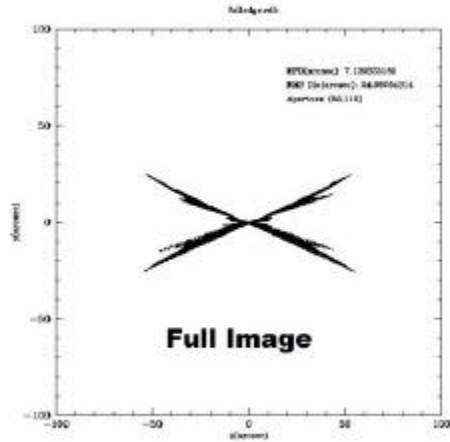
| Aperture	HPD (arc-sec)
50 de: in center	7
2 deg: at edge	76
2 deg: 4 deg from edge	36
2 deg: 14 deg from edge	11
2 deg: in center	< 1

Constellation-X

OAP2 Thermal Contributors

- **OAP2 has glass optics with a CTE of 7.2 ppm/degrees C**
- **Housing material (Ti) chosen to minimize Glass/housing CTE mismatch (Ti is 9.5 ppm/degree C)**
- **OAP2 is sensitive to both differences in average temperature and to thermal gradients**

Error Contributor	HPD Sensitivity	Tolerance	Contribution
	Arc-sec/ degree C	Degree C	HPD (Arc-seconds)
Thermal soak (per degree C)	0.3	1.0	0.3
Epoxy Bi-layer effects, per C	1.0	1.0	1.0
Axial Gradient (Z in Figure 5)	0.2	0.5	0.1
Transverse Gradient (Y in Figure 5) (Ti bars join P & H Hsgs)	7.3	0.1	0.73
Vertical Gradient (X in Figure 5)	1.5	0.5	0.75
RSS			1.48

Constellation-X

OAP2 Thermal Control System
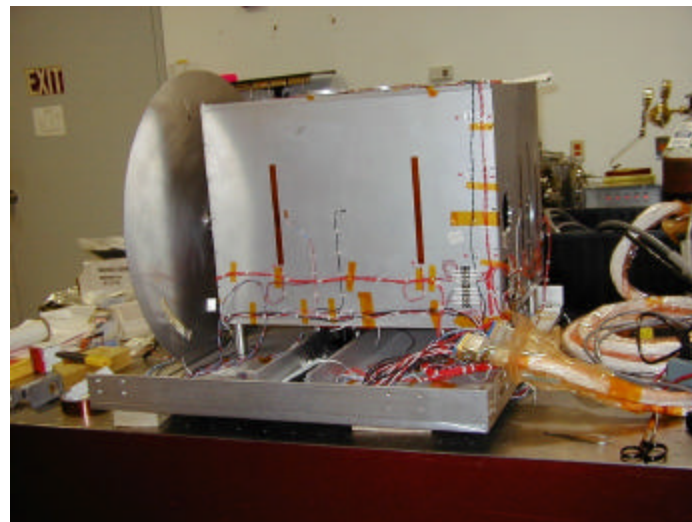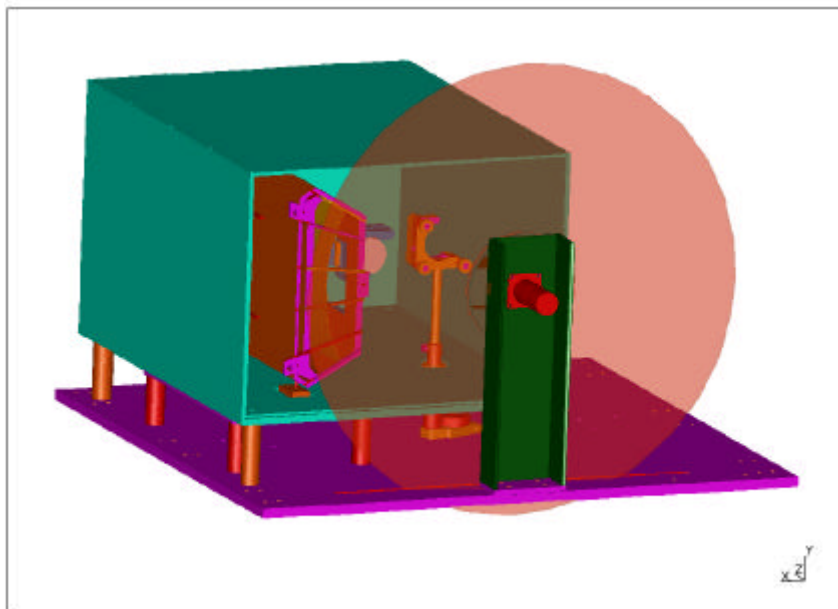
- **Thermal control system and motor driven aperture wheel to be used in OAP2 x-ray testing.**
- **Evaluate thermal sensitivities by varying control set-points**
- **Evaluate gravity effects by scanning a small aperture over the extent of the OAP2 aperture**

Constellation-X